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Article

Characterization of Alginate from Drifted Pelagic *Sargassum natans* and *Sargassum fluitans* Along the Moroccan Atlantic Coast

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Abstract

The unprecedented influx of pelagic *Sargassum* represents both a serious ecological concern and a potential opportunity regarding biopolymer production. Assessing the quality, preservation status, and processing potential of these species is crucial to transforming this environmental challenge into a sustainable benefit for industrial valorization. In the present work, we investigated the alginate yields ($21.2 \pm 0.57\%$ and $18.1 \pm 0.11\%$ dw) and the structural characteristics of sodium alginates extracted from *Sargassum natans* and *Sargassum fluitans* encountered drifting along Moroccan coasts, respectively. The FTIR analysis indicated that the extracted alginates from both species exhibited similar spectral profile of the commercial alginate obtained from Sigma-Aldrich. The ¹H NMR spectra of the extracted alginates displayed characteristic signals for monads M and G and diads MM, GG, and MG/GM, consistent with M/G ratios above 1, with fairly abundant heteropolymeric fractions (F_{GM}/F_{MG}) accounting for more than 52% of the polymer diads. Intrinsic and molecular weight analyses revealed differences between *S. natans* ($[\eta] = 1.39$ dL/g; $M_w = 0.65 \times 10^{-5}$ g/mol) and *S. fluitans* ($[\eta] = 0.80$ dL/g; $M_w = 0.37 \times 10^{-5}$ g/mol). Both values are comparable to commercial alginate but remarkably lower in viscosity. Consequently, alginates from these species are foreseen to form elastic, flexible, and softer gels, making them suitable for applications such as drug delivery, cancer therapy, bioactive encapsulation, controlled nutrient release, and environmental remediation.

Keywords: pelagic *Sargassum*; alginates; spectroscopy analysis; intrinsic viscosity; molecular weight; Moroccan coastline



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1. Introduction

In the vast expanse of the North Central Atlantic Ocean, a floating brown seaweed grows abundantly, identified as *Sargassum natans* and *Sargassum fluitans* (Phaeophyceae, Fucales) [1]. The origin points of these blooms, including the Sargasso Sea, Gulf of Mexico, and the Northern Equatorial Recirculation Region, highlight the oceanic pathways

that concentrate and transport this seaweed across regions [2,3]. These pelagic species now appear regularly along West African coasts, as confirmed by satellite imagery near Senegal [4]. Spring 2024 marked the beginning of significant pelagic *Sargassum* wash ups, with perhaps millions of tones coming ashore on the Canary and Azores Islands [5,6]. Meanwhile, large floating mats of these species were also transported by ocean currents and storms, causing them to drift along the Atlantic coast of Morocco for the first time (Figure S1 in the Supplementary Material). This extraordinary manifestation is largely driven by anthropogenic pressures and climatic factors (i.e., global warming), along with other acknowledged causes [4,7]. Nevertheless, the scientific literature widely regards their rapid proliferation as an invasive phenomenon due to disruptive ecological impacts, including displacement of native species, oxygen depletion in coastal waters, and economic losses in fisheries and tourism [3,7,8].

Despite the challenges, these pelagic species possess significant but unexploited potential. They are abundant in bioactive compounds that can be converted into high-value products for diverse industries, including agriculture, pharmaceuticals, and biotechnological engineering [9]. Among their valuable components is alginate, a linear heteropolysaccharide of brown seaweeds composed of β -D-mannuronic acid (M) and α -L-guluronic acid (G) assembled in homogeneous (MM or GG) and heterogeneous (MG or GM) blocks [9]. Nowadays, alginate is one of the most utilized polysaccharides across various industries, which creates a high demand for identifying and analyzing new raw materials for its extraction, particularly for sodium alginate [10]. The composition of these extracted alginates is a key concern, because of the wide range of potential applications, which rely on their structural features [11]. The literature reports that molecular mass, intrinsic viscosity, M/G ratio, block structure, and the degree of chain polymerization can influence their physico-chemical properties [9,12]. Analogously, its functional versatility comes from the ability of high G-blocks to form strong and reversible gels. Meanwhile, low G-blocks lead to soft and elastic gels [11]. Brown algae such as *Laminaria hyperborea*, *L. digitata*, *L. japonica*, *Ascophyllum nodosum*, and *Macrocystis pyrifera* are the main raw materials used in industrial alginate production [13]. However, *Sargassum* species produce alginate with smaller quantities and low viscosity [11]. The viscosity, stabilizing capacity, and gelling properties of alginate are essentials to identify its suitability for industrial applications. A strong gel with high viscosity is typical for food and pharmaceutical industries [9,11].

This study represents the first attempt to explore the valorization of *S. natans* and *S. fluitans* transported from the Tropical Atlantic and deposited along the Moroccan Atlantic coast as a source of alginate. Given that similar strandings have already been reported in the Canary and Azores Islands [5,6], these drifts are not isolated events but part of a recurring transatlantic phenomenon that is expected to continue. We hypothesized that the recurrent *Sargassum* inundations provide an opportunity to assess the influence of long-distance transport on both the quality and quantity of alginates, with transport-related environmental exposure expected to affect alginate yield and composition. The aim of this work is to bridge the sustainable management of these coastal drift biomasses with the extraction of high-value biomolecules, thereby contributing not only to local resource utilization but also to circular bioeconomy strategies of global relevance that address both environmental and market-driven demands.

2. Materials and Methods

2.1. Sampling and Identification of the *Sargassum* Species

The pelagic *Sargassum* were encountered across a broad stretch of the Atlantic coast of Morocco (Figure S1 in the Supplementary Material), where they had drifted from the Tropical Atlantic. Studied samples were collected in April 2024 from the El Jadida coastline

(33°14'42.9" N 8°28'46.4" W) and subjected to analysis. The samples were identified at the Phycology, Biodiversity and Blue Biotechnology research unit of the Faculty of Science of El Jadida (Morocco) using taxonomic keys described by Parr [14]. In differentiating between the *Sargassum* specimens, certain morphological features are key: *S. fluitans* is characterized by lanceolate leaves, small thorns along the stipes, and a dark olive color. Conversely, *S. natans* has thinner leaves, smooth stipes, and thornless branches [14] (Figure 1). The collected specimens were washed with tap water and deionized water to remove debris and then dried at 50 °C until a constant weight was achieved.

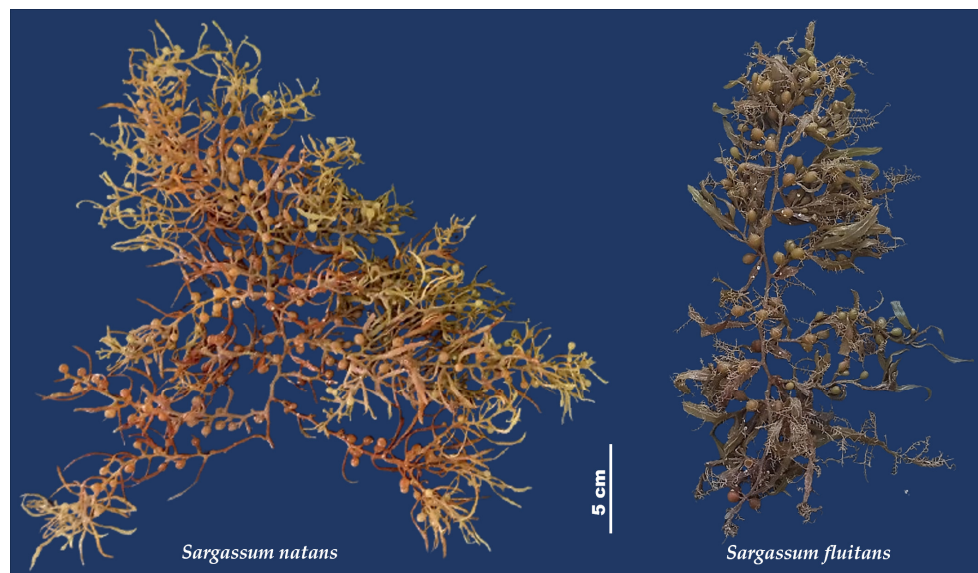


Figure 1. Photographs showing whole thalli of *S. natans* and *S. fluitans*. Scale bar = 5 cm.

2.2. Alginate Extraction

The alginates were extracted according to Calumpong et al. [15] with some modifications. Briefly, *Sargassum* dry biomass was pretreated overnight in 2% w/w formaldehyde to remove phenolic compounds. The seaweeds were washed with distilled water, and 0.2 M HCl was added to form the alginic acid. Samples were left overnight, washed with distilled water, and extracted in 2% sodium carbonate. The extracted sodium alginate was filtered by muslin cloth after being precipitated in ethanol, washed by acetone, and recovered by oven drying at 50 °C. Yields were determined from the dried biomass. Standard-grade sodium alginate obtained from Sigma-Aldrich Chemical was used for comparison.

2.3. Intrinsic Viscosity $[\eta]$ and Molecular Weight (M_v)

Measurements of the intrinsic viscosities $[\eta]$ were carried out from sodium alginate solutions in 0.1 M NaCl at concentration of 0.1 to 1% wt. using a Ubbelohde viscosimeter with a 0.5 mm capillary diameter. The efflux time of the solvent at the different concentrations prepared was measured in triplicate, and the average values were used to determine the relative viscosities.

The intrinsic viscosity $[\eta]$ is defined by the Huggins equation in which η_{sp} represents the specific viscosity, C represents the concentration of the solution, and K_H represents the Huggins constant:

$$\eta_{sp}/C = [\eta] + K_H[\eta]^2 C$$

The average molecular weight (M_v) was determined by the intrinsic viscosity using the Mark–Houwink–Sakurada equation, $[\eta] = k(M_v)^a$, where k and a are empirical constants. As proposed by Torres et al. [16], the values of k and a used to calculate the average molecular weight (M_v) were 0.023 and 0.984.

2.4. FTIR Spectroscopy Analysis

FTIR spectroscopy analyses of extracted and commercial sodium alginate were carried out for wavenumbers ranging from 400 to 4000 cm^{-1} with a resolution of 4 cm^{-1} using a Nicolet Impact 400 D FTIR Spectrometer (Nicolet Impact, Madison, WI, USA). The processing of the infrared spectra plots was measured using OMNIC 7.1 software (Nicolet, Madison, WI, USA).

2.5. Proton Nuclear Magnetic Resonance Spectroscopy (^1H NMR)

Samples of extracted and commercial alginate were dissolved in D2O and dried several times prior to NMR spectrum acquisition. ^1H -NMR was carried out on the spectrometer AV II 400 MHz (Bruker Corporation, Billerica, MA, USA) using a 5 mm Triple Resonance Broadband Inverse probe, with temperature regulated at 343 K. ^1H -NMR spectra were recorded by presaturation during the relaxation delay and mixing time.

3. Results and Discussion

3.1. Physical Properties

3.1.1. Alginate Yields

The alginate yields of the pelagic *Sargassum* species (*S. fluitans* and *S. natans*) encountered on the northeastern Atlantic coast of Morocco are within the range reported from other *Sargassum* sources, showing considerable variability (Table 1).

Table 1. Sodium alginate yields of *S. natans* and *S. fluitans* compared to other *Sargassum* species.

Algal Species	Alginate Yields (% dw)	References
<i>Sargassum fluitans</i>	21.1–22.8%	[17]
<i>Sargassum oligocystum</i>	16.3–20.5%	
<i>Sargassum natans</i>	23%	[12]
<i>Sargassum vulgare</i>	17%	
<i>Sargassum natans</i> *	7–19%	[18]
	28%	[19]
<i>Sargassum fluitans</i>	21.1%	[20]
Pelagic <i>Sargassum</i> *	17.75–30.19%	[21]
Pelagic <i>Sargassum</i>	2.62–9.11%	[22]
<i>Sargassum natans</i> I *	11.13%	
<i>Sargassum natans</i> VIII *	12.18%	[23]
<i>Sargassum fluitans</i> III *	9.36%	
<i>Sargassum oligocystum</i>	37%	[24]
<i>Sargassum filipendula</i>	17%	[25]
<i>Sargassum fluitans</i> *	45%	[26]
<i>Sargassum fluitans</i> *	21.2 ± 0.57%	This study
<i>Sargassum natans</i> *	18.1 ± 0.11%	

* Drifted biomass.

The obtained alginate yields were 21.2 ± 0.57% dw and 18.1 ± 0.11% dw for *S. fluitans* and *S. natans*, respectively. These findings fall above the lower range reported for pelagic *Sargassum* (2.62–9.11%) but remain within the range of 12–45% typically obtained from brown seaweeds with industrial production exploitation [22,24,27]. While these results suggest higher yields than other studies conducted on the same species [18,22], they still face

limitations as a source of commercial alginate. Furthermore, Table 1 distinguishes between drifted and non-drifted pelagic *Sargassum*. This differentiation emphasizes the unique characteristics of pelagic species: drifted samples may undergo environmental exposure that alters their biochemical composition, whereas non-drifted specimens reflect fresher conditions. Although the dataset is limited, this distinction is relevant for understanding pelagic *Sargassum*, even though environmental exposure does not appear to strongly affect total alginate yield. Accordingly, alginate remains one of the most versatile polysaccharides, with various applications in the food, textile printing, and pharmaceutical industries and in the biomedical and bioengineering fields [8,27]. Mohammed et al. [18] stated that pelagic *Sargassum* collected in the Caribbean produces sodium alginate that could be employed for packaging and encapsulation. Calcium alginate from the same species revealed potential as an effective biosorbent for heavy metal ions [28]. The discrepancy showcases wide and diverse future potential applications of alginate, even at moderate yields, emphasizing the need for standardized methodologies and further biomasses.

3.1.2. Intrinsic Viscosity $[\eta]$ and Molecular Weight (Mw)

The Intrinsic viscosity reflects the hydrodynamic volume occupied by a macromolecule under infinite dilution in a defined solvent at a given temperature. It is influenced by factors such as molar mass and the composition and sequence of mannuronic (M) and guluronic (G) residues [16]. The resulting outcome of their intrinsic viscosity and molecular weight are shown in Table 2. The intrinsic viscosity in 0.1 M NaCl at 25 °C measured for *S. natans* alginate ($[\eta] = 1.39$ dL/g) significantly exceeded that of *S. fluitans* ($[\eta] = 0.80$ dL/g), revealing a higher polymer extension in *S. natans*. Previous studies in *S. fluitans* are highly variable with $[\eta]$ ranging from 0.57 to 11.6 dL/g, indicating that environmental factors and extraction protocols might strongly influence the viscosity of alginates [26,29]. Moreover, the low viscosity of the extracted alginate might lack the required gelling features needed for applications [16]. The molecular weight of commercial sodium alginate is typically ranging from 60 to 700 kDa depending on application [9]. A very low average molecular weight of 0.65×10^{-5} g/mol was estimated for *S. natans* and 0.37×10^{-5} g/mol for *S. fluitans*. Notwithstanding, the results remain pronouncedly low compared with those found in the literature. However, the molecular weight of the two species is within the same order as commercial alginate 0.85×10^{-5} g/mol. Despite comparable Mw values, their intrinsic viscosities are lower than that of commercial alginate ($[\eta] = 1.83$ dL/g). This highlights potential differences in polymer conformation, block distribution, or extraction conditions [12]. The higher viscosity and molecular weight of *S. natans* compared to *S. fluitans* suggest longer polymer chain length, which could enhance gel forming capacity. In contrast, the lower viscosity of *S. fluitans* points to easier processability, which can help in applications requiring reduced solution viscosity. Meanwhile, *S. natans* continues to have low intrinsic viscosity and molecular weight compared to other species, as presented in Table 2. Furthermore, low-viscosity alginate has become a multifaceted material with broad applications across biomedical and industrial fields [11,16]. Its biocompatibility and capacity to control particle size and surface charge make it especially effective for designing drug delivery systems [13,30]. For instance, in cancer therapy, alginate-based nanocarriers have been investigated for treating neuroblastoma, where they improve drug efficacy, minimize toxicity to healthy neuronal cells, and enhance overall therapeutic outcomes [31]. Beyond cancer treatment, low-viscosity alginate is particularly valuable for encapsulating bioactive compounds including proteins, phlorotannins, and antioxidants. Research indicates that alginate beads significantly boost the absorption of these bioactives during gastrointestinal digestion [30]. Overall, the evidence highlights our low-viscosity alginates from *S. fluitans* and *S. natans* as a multifunctional platform with wide-ranging

potential in biomedical applications, where controlled release and biocompatibility are essential (e.g., drug delivery, cancer therapy, and bioactive encapsulation), as well as in food and environmental domains, such as nutrient release and remediation processes. Viscosity measurements further reflect differences between drifted and non-drifted pelagic *Sargassum*, with less polymer degradation (Table 2). These observations suggest that environmental exposure may influence polymer properties, but both categories provide versatile alginate suitable for diverse applications.

Table 2. Intrinsic viscosity $[\eta]$ and molecular weight (Mw) of alginate extracted from pelagic species *S. fluitans* and *S. natans* in comparison with other *Sargassum* species.

Species	$[\eta]$ (dL/g)	Mw $\times 10^{-5}$ (g/mol)	References
<i>Sargassum natans</i> *	-	3.14–3.2	[19]
<i>Sargassum fluitans</i>	6.3	3	[29]
<i>Sargassum fluitans</i> *	0.57–11.6	-	[26]
<i>Sargassum vulgare</i>	4.1–6.9	1.94–3.3	[16]
<i>Sargassum asperifolium</i>	15.2	7.34	[32]
<i>Sargassum latifolium</i>	8.7	4.16	
<i>Sargassum natans</i> *	1.39	0.65	This study
<i>Sargassum fluitans</i> *	0.80	0.37	
Commercial alginate	1.83	0.85	

* Drifted biomass.

3.2. Chemical Properties

3.2.1. FTIR Spectroscopy Analysis

The infrared spectra of alginates extracted from the pelagic *Sargassum* species compared to that of the referenced commercial sodium alginate given in Figure 2 are very close to the standard, with both showing characteristic peaks. The given spectra share a similar pattern to the previously reported FTIR spectrum on the *Sargassum* species, showing sodium alginate as the predominant polysaccharide extracted from these species [19]. A broad band at $\sim 3250\text{ cm}^{-1}$ was assigned to O-H stretching vibrations, typical of hydroxyl groups in polysaccharides. A weaker band near 2920 cm^{-1} corresponds to C-H stretching vibrations [33]. The ($2000\text{--}600\text{ cm}^{-1}$) region represents the fingerprint region in which several characteristic bands of alginates were observed. The absorption around 1600 cm^{-1} corresponds to the asymmetric stretching of carboxylate (RCOO^-) [34]. The carboxylate groups indicate that the alginates were extracted under alkaline conditions, resulting as alginates salts [12]. The peaks around 1405 cm^{-1} are interpreted as the symmetric stretching of carboxylate groups, with a minor contribution from C-OH deformation [35]. Overall, our findings align with previous studies, where the bands observed at 1085 and 1025 cm^{-1} were assigned to vibrations of mannuronic and guluronic residues [10]. Furthermore, FTIR analysis revealed no peak within the $1230\text{--}1280\text{ cm}^{-1}$ region, which is typically associated with sulphated polysaccharides [36], indicating that the obtained sodium alginate was highly purified. The anomeric region around $950\text{--}750\text{ cm}^{-1}$ is one of the most frequently analyzed regions in carbohydrates [34]. The bands at $\sim 950, 904, 870,$ and 805 cm^{-1} were attributed to the guluronic and mannuronic acid residues, consistent with earlier studies [33,34].

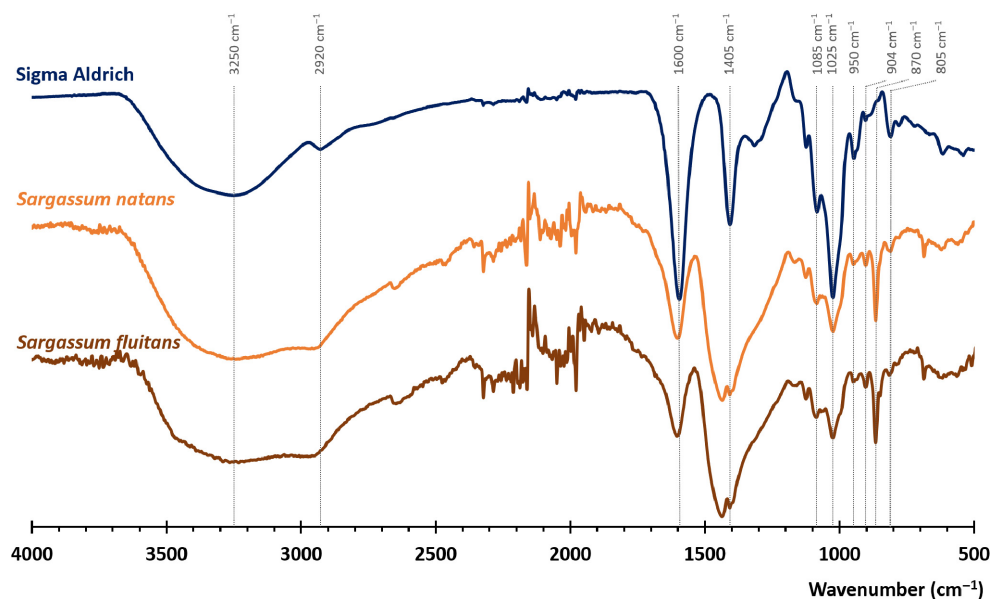


Figure 2. FTIR spectra of Sigma Aldrich commercial sodium alginate and alginates extracted from the encountered *S. natans* and *S. fluitans*.

3.2.2. Proton Nuclear Magnetic Resonance Spectroscopy (^1H NMR)

^1H NMR spectroscopy is the main analytic technique used to elucidate the sequence and distribution of the uronic acid residues [19]. Figure 3 illustrates the ^1H NMR spectra of the alginates extracted from the pelagic *Sargassum* species closely resembling that of commercial sodium alginate, with three characteristic signals attributed to the anomeric hydrogen of guluronic acid (G) at 5.1–5.2 ppm (signal I), the anomeric hydrogens of mannuronic acid (M1), the H-5 of alternating blocks (GM-5) overlapping at 4.7–4.85 ppm (signal II), and the H-5 of guluronic acid residues in the homopolymeric G blocks, at 4.5–4.6 ppm (signal III).

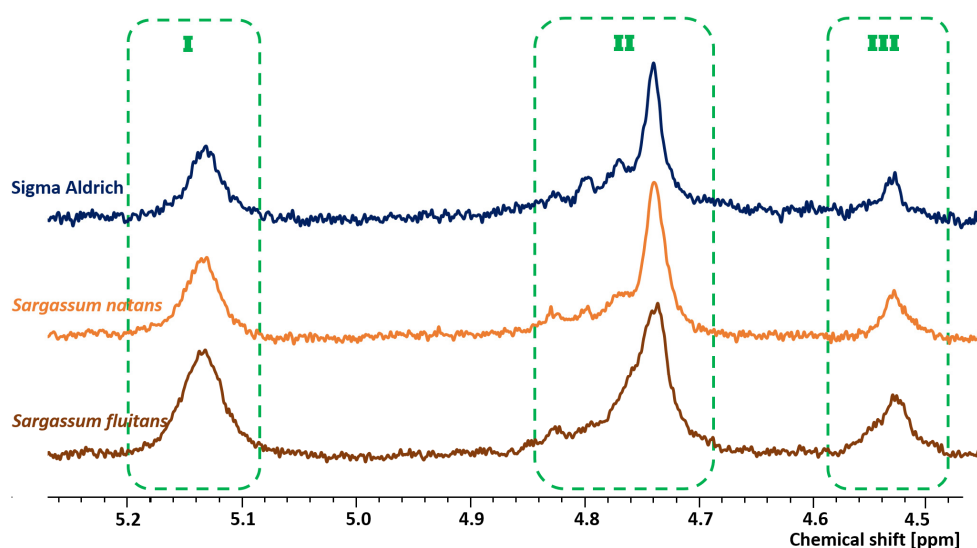


Figure 3. ^1H NMR spectra of commercial sodium alginate obtained from Sigma Aldrich and alginates extracted from the pelagic species *S. fluitans* and *S. natans*. I: signal attributed to anomeric hydrogen of guluronic acid (G). II: signals of H-1 on mannuronic acid (M) and H-5 on GM alternating blocks. III: signal corresponding to the H-5 of homopolymeric G residues.

The structural composition of alginates, defined by the ratio, arrangement of guluronic and mannuronic acid residues, and η parameter, is a key factor determining their gelling properties, which was calculated following the equations of Grasdalen et al. [37]:

$$F_G = A I / (A II + A III)$$

$$F_M = 1 - F_G$$

$$F_{GM} = F_{MG} = F_G - F_{GG}$$

$$F_{MM} = F_M - F_{MG}$$

$$M/G = (1 - F_G) / F_G$$

$$\eta = F_{MG} / (F_M - F_G)$$

Previous studies have reported most species with $F_G > 0.6$ (Table 3) and M/G ratios below 1, indicating strong gel-forming ability due to their high G-blocks [12,17–20,26]. The M/G ratios found in the present study were above 1 and are in agreement with the ratios found in [23], indicating flexible gel-forming potential due to relatively high M-blocks ($F_M = 0.52$ – 0.56) and suitability for applications such as encapsulation and film formation [8,27]. Moreover, M-rich alginates are well-known for their wound-healing properties, suggesting that the alginates obtained in this study may also hold promise for biomedical applications in this field [38]. These dissimilarities can be postulated to be a result of geographical location as well as extraction protocol. A higher M/G ratio of 1.87 was found for the commercial sodium alginate.

Table 3. Mannuronic and guluronic acid compositional data of alginate extracted from pelagic species *S. fluitans* and *S. natans* in comparison with other *Sargassum* species.

Species	F _G	F _M	F _{GG}	F _{GM}	F _{MG}	F _{MM}	M/G	η	References
<i>Sargassum natans</i> 1 *	0.35	0.65	-	-	-	-	1.87	-	
<i>Sargassum natans</i> VIII *	0.34	0.66	-	-	-	-	1.97	-	[23]
<i>Sargassum fluitans</i> *	0.35	0.65	-	-	-	-	1.94	-	
<i>Sargassum natans</i>	0.68	0.32	0.61	0.07	0.07	0.25	0.47	0.32	[12]
<i>Sargassum fluitans</i>	0.64	0.36	0.55	0.08	0.08	0.28	0.57	0.34	[17]
	0.76	0.24	0.66	0.08	0.08	0.13	0.31	0.43	[20]
	0.45	-	0.28	-	-	-	-	-	[29]
<i>Sargassum fluitans</i> *	0.84	0.16	0.81	0.03	0.03	0.13	0.19	-	[26]
<i>Sargassum natans</i> *	0.67	0.33	0.59	0.09	0.09	0.24	0.49	0.40	[19]
	0.66	0.34	0.62	0.04	0.04	0.32	0.51	0.18	[18]
<i>Sargassum muticum</i>	0.49	0.51	0.15	0.34	0.34	0.17	1.04	1.35	[39]
<i>Sargassum vulgare</i>	0.44	0.56	0.43	0.01	0.01	0.55	1.27	0.04	[16]
	0.59	0.41	0.49	0.10	0.10	0.31	0.7	0.41	[12]
<i>Sargassum thunbergii</i>	0.66	0.34	0.48	0.17	0.17	0.17	0.53	0.76	
<i>Sargassum polycystum</i>	0.82	0.18	0.77	0.1	0.1	0.12	0.21	0.68	[24]
<i>Sargassum filipendula</i>	0.56	0.44	0.45	0.11	0.11	0.33	0.78	0.45	[25]
<i>Sargassum fluitans</i> *	0.48	0.52	0.22	0.26	0.26	0.26	1.08	1.03	
<i>Sargassum natans</i> *	0.44	0.56	0.16	0.28	0.28	0.28	1.27	1.12	This study
Commercial alginate	0.35	0.65	0.16	0.19	0.19	0.46	1.87	0.83	

* Drifted biomass.

Based on the ¹H NMR results for both studied species (Table 3), the heteropolymeric regions ($F_{GM}/F_{MG} = 52$ – 56%) are relatively high compared to homopolymeric fractions

($F_{MM} = 26\text{--}28\%$; $F_{GG} = 16\text{--}22\%$). The description of the alginate sequence can be further refined via the parameter η , which provides insight into the distribution of the blocks. Moreover, η values below 1 indicate a predominance of homopolymeric blocks (MM and GG), a value of η equal to 1 corresponds to a completely random sequence, and values between 1 and 2 suggest an alternating pattern of MG and GM blocks [37]. The η values of the extracted alginates exceeded 1 (Table 3), suggesting a polymer sequence characterized by a dominance of heteropolymeric region. When considering the drifted and non-drifted *Sargassum* species, subtle differences were observed. While some studies report drifted material as being either mannuronic-rich or guluronic-rich [18,19,23,26], our results provide a predominance of heteropolymeric fractions (F_{MG}/F_{GM}) in both species. The presence of these heteropolymeric blocks likely contributes to increased rigidity, suggesting that the thalli retain their structural integrity during drift. This is in agreement with observations that non-drifted species retain higher G-blocks [12,17,20], hypothetically suggesting that the drift occurred rapidly or over relatively short distances, limiting structural degradations. Species-specific alginate profiling can act as a guide for targeted biotechnological applications, including gelling agents, biomedical applications, and drug delivery systems [13,39]. Furthermore, alginate hydrogels have garnered significant attention in biomedical applications because of their hydrophilicity, biodegradability, and outstanding biocompatibility [40]. Sodium alginate also demonstrates antibacterial properties by interacting with bacterial membranes, which aids wound healing by preserving a moist environment and preventing bacterial infiltration. Due to these characteristics, sodium alginate has been extensively researched for use in wound dressings and tissue engineering [40,41]. Overall, our findings show no differences between the two species; a more uniform alginate structure leads to intermediate physical properties. This similarity between the two species might mean that environmental factors shaped their alginate biosynthesis in the same way. Therefore, these species are suitable for industries requiring flexibility, viscosity, and stability.

4. Challenges and Opportunities

The physical and chemical characterization of the alginate extracted from drifted tropical *Sargassum* (*S. fluitans* and *S. natans*) provides insights into its potential utility; however, several practical challenges and opportunities must be considered. Firstly, alginate quality may deteriorate during transit from the open ocean to the shore as a result of natural degradation, potentially restricting its use in premium applications that demand uniform purity [42]. Secondly, drift occurrences are seasonal and sporadic, leading to an irregular supply that could hinder large-scale industrial adoption. Thirdly, substantial biomass volumes often accumulate rapidly, posing challenges for prompt processing; while drying and storage techniques can alleviate this, effective operational strategies are essential to manage these influxes [43]. Lastly, material from drifted pelagic *Sargassum* varies from that of freshly collected sources, which generally provide more reliable quality. Addressing these limitations underscores opportunities for further investigation, such as customized processing methods and improved storage solutions to supplement the intermittent nature of drift events.

5. Conclusions

In the present work, we investigated the yield, the spectroscopic (FTIR and ^1H NMR) characterization, and the intrinsic viscosity of pelagic *Sargassum* (*S. fluitans* and *S. natans*) encountered on the Moroccan coastline. The extracted alginate gave yields within the range of the *Sargassum* genus (18.1–21.2% dw) for *S. fluitans* and *S. natans*, respectively. FTIR spectroscopy analysis revealed similarity between the extracted alginate spectra of

the two species and the commercial alginate. ^1H NMR spectroscopy of the extracted alginates displayed a dominance of mannuronic acid (F_M) for both species. However, the heteropolymeric fractions (F_{GM}/F_{MG}) dominated the polymer sequence compared to homopolymer fractions (F_{MM} and F_{GG}), balancing elasticity and flexibility. Intrinsic viscosity and molecular weight analyses revealed differences between *S. natans* ($[\eta] = 1.39$ dL/g; $M_w = 0.65 \times 10^{-5}$ g/mol) and *S. fluitans* ($[\eta] = 0.80$ dL/g; $M_w = 0.37 \times 10^{-5}$ g/mol). Both values are comparable to commercial alginate in order of magnitude but markedly lower in viscosity, suggesting structural or compositional differences. Consequently, alginates from these two species are expected to form softer gels and more fluid solutions, favoring applications such as stabilization, dispersibility, encapsulation, or drug delivery systems.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/physchem5040051/s1>, Figure S1: Overview of the wide distribution of the drifted pelagic *Sargassum* along the Atlantic coast of Morocco. (A) Geographic localization of the sampling site, with red dots revealing the points of species occurrence. (B) Accumulated drift samples along El Jadida coastline.; Figure S2: Anomeric regions in 400 MHz— ^1H NMR spectra of Sigma-Aldrich, *Sargassum natans*, and *Sargassum fluitans* sodium alginates using D_2O as solvent.

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